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# Public Transit Capacity and User's Choice: An Experiment on Downs-Thomson Paradox

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## Abstract

We study the Downs-Thomson paradox, a situation where an additional road capacity can cause an overall increase in transport generalized cost and therefore a decrease in welfare for transport users. To this end, we build an experiment based on a double market-entry game (DMEG) where users have to choose between road and public transit after that the operator has chosen public transit capacity. The optimal strategy for operator is to minimize capacity, and the equilibrium for users depend on the endogenous public transit capacity compared to exogenous road capacity. The most important result is that we observe the Downs-Thomson paradox empirically in the laboratory: An increase in road capacity causes shift from road to rail and, at the end, increases total travel costs. But the contrary is not true: A decrease in road capacity does not cause lower total travel costs, which is in contradiction with our theoretical model. Results also show that the capacity chosen by operator differs from Nash prediction, levels being significantly higher than those predicted by our model. Moreover, users coordinate remarkably well on Nash equilibrium entry rate while capacity has been chosen by operator.

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# 1 Introduction

In transport economics, an increase in road capacities, by causing shifts from public transit to private transport, could lead to a new traffic equilibrium where total transport costs are higher. Indeed, by implementing an additional road capacity (eg a new route or more generally a new transport alternative), road speed increase, attracting public transit users towards road transport. Then, as public transit traffic decreases, there is a loss of revenue for public transit operator, who, in the absence of subsidies, might raise fare or cut service. This well-known phenomenon has been called "Downs-Thomson" paradox (Downs, 1962; Thomson, 1977 ; Mogridge et al, 1987 ; Mogridge, 1990a,b, Mogridge, 1997 ; Arnott & Small, 1994 ; Jones, 2002, Litman, 2005). Such a phenomenon is an important argument for people who are defending urban pricing for private cars and consequently investment in (collective) high-capacity systems, in order to increase journey speeds (See Webster, 1985).

Although the possibility of the Downs-Thomson (DT) Paradox seems to be well accepted, there is little evidence in the literature to indicate when it might occur. Holden, 1989 suggests that it may occur "in a city like London, where a significant fraction of peak traffic is carried on an extensive rail network". Mogridge et al , 1987 suggest that it may occur by "*allocating even more space to roads when roads are a less efficient carrier of the flow of traffic*". These statements are mainly qualitative, based on intuition and experience.

Economic experiments about congestion tend to be in a growing number (Selten et al., 2007 ; Zieglmeier et al., 2007 ; Hartmann, 2006 ; Rapoport et al., 2005 ), mainly about road traffic (departure time or route choice) but, to our knowledge, no experiment exists on the possible interactions between *public transit* and *road traffic*, as this interaction could be for instance investigated in the Downs-Thomson Paradox.

The aim of this paper is to provide empirical support about this paradox. To this end, we build an economic experiment in which subjects have to choose between two markets, e. g road and public transit. Our theoretical framework is built upon a class of coordination games named Market Entry Game (Selten & Güth, 1982 ; Gary-Bobo, 1990). Basically, in a MEG, players have to choose to enter a market or not to enter: The payoff is a decreasing function of the number of entrants whereas option to stay out gives a constant payoff. In such games, Nash equilibriums will give excess entry, implying a social dilemma.

Such games are a very simple and accurate stylisation of congestion process that frequently occur in the transport field, firstly because such game implements a negative externality of entry decision on individuals' payoffs that are to enter, which implies an efficiency problem. Secondly, at a theoretical level, such games are characterized by many equilibriums that imply high levels of coordination for players, such equilibriums being not welfare maximizing.

The main problem if we consider transport choice is that users can choose between alternatives (routes, modes, departure times, etc.). The idea is that all of these alternatives give to users a certain utility, this utility being potentially affected by congestion, or, more generally, by the total number of users who choose this specific alternative. It is not the case in the usual MEG. As we are interested in choices between modes, we use a Double Market Entry Game framework in order to deal with such choice alternatives, where the user can choose between two options, both being affected by traffic level on each option. The second originality of our theoretical framework is to deal with *crossed-externalities*, e.g a situation where the choice of player  $i$  choosing X affects the situation of player  $j$ , even if player  $j$  is to choose the Y option. Last but not least, the externality produced by one market is negative, whereas the other market gives a positive externality for individuals choosing it.

But such phenomenons of crossed-externalities are not relevant only for transport field, of course. For instance, recently, some politicals in France claim to decrease levels of taxes on

oil in order to absorb the impact of exploding oil prices for households. The impact of that could be that, for residential heating especially, households are first incited to consume more oil and second, households are incited to differ decisions which could reduce oil consumption, as solar or geothermic solutions for heating. This will produce additional negative externalities (CO2 emissions and so on) and also reduce positive externalities linked to the choice of more ecological solutions. Many examples of such phenomenons could be observed in economics, and our theoretical model can be used for investigating situations that do not deal only with transport economics.

Our experimental game is a two-stage game where a first mover A (the operator) has to choose the public transit capacity. Then, given a road capacity that is fixed exogenously by the experimenter (the planner), subjects B (travellers) have to choose between road transport (option X) and public transit (option Y). As in a usual MEG, the payoff from the first market decreases with number of entrants and increases with exogenous capacity. For the second market (public transit) things are quite different: The payoff from the second market increases both with the number of entrants and with the capacity chosen by the operator, i.e. player A. Thus, entry generates negative externality on the road market, and, on the contrary, entry generates a positive externality on the public transit market. At the traffic users Nash equilibrium, the entry rate on road increases with exogenous capacity of road and decreases with endogenous capacity of public transit. As the marginal revenue of public transit entry is less than the marginal revenue of road entry, the optimal strategy for player A is to fix the lowest possible level for public transit capacity; The Subgame Perfect Equilibrium corresponds to a situation where player A chooses the minimum capacity, implying too much entry on road and lack of efficiency for the transport system (Transport cost is not minimized at the traffic equilibrium). In such a game, an exogenous increase in road capacity generates shifts from public transit to road that leads to a new traffic equilibrium where efficiency level is lower.

Our experimental design consists in groups of 15 subjects with 1 subject A and 14 subjects B. At each period, subjects A and B play a two-stage game where subject A chooses first a capacity level for public transit. Being informed about A's choice, subjects B have to choose between two options, X (road) and Y (public transit). In each session, subjects play 2 treatments of 20 periods (within-subject design). For some sessions, subjects play first 20 periods of low capacity for road market and second 20 periods of high capacity for road market (condition ADD). In other sessions, subjects play first the high capacity condition during 20 periods and then play 20 periods in low capacity condition (condition DEL).

16 sessions (8 sessions in the ADD condition and 8 sessions in the DEL condition) of 15 subjects (namely 240 participants, students from various origins, economists, lawyers, psychologists, etc.) have been held in LABEX (LABoratory for EXperiments in economics and management), University of Rennes 1 from January to April 2008 under the ZTREE platform (see Fischbacher, 2007).

Our main results indicate that participants A reach remarkably well the entry rate on each market that is predicted by Pure Strategy Nash Equilibrium. It is far from being the case for participant A, who chooses average capacity level significantly above the optimal level given by Nash equilibrium. Moreover, we observe Downs-Thomson Paradox in the laboratory, e.g. an increase in road capacity for a given group does increase total travel times and therefore is associated to lower efficiency levels. But we do not observe the reverse phenomenon, that is a decrease in road capacity does not decrease significantly total travel times.

In a first section, we will make some literature review concerning our initial question (Downs-Thomson Paradox). The second section is devoted to our theoretical model, which is a Double Market Entry Game both with a negative and a positive externality. Then, we present in a third section the experimental design, and parameters that had been implemented in the lab. The

fourth section presents experimental results and the last one is to conclude.

## 2 Downs-Thomson Paradox and Mogridge's conjecture

Martin J.H. Mogridge in his 1990's book "*Travel in towns: Jam yesterday, jam today and jam tomorrow?*" observes that, especially in London, increasing road capacity tends to increase traffic congestion: all road investment in a congested urban area, will reduce the average speed of the transport system as a whole – for road and public transport (e.g. urban mass transit). He therefore conjectures that improving collective transport could increase welfare. In fact, Mogridge's analyze is a renewed version of the well-known Downs-Thomson paradox (Downs, 1962 ; Thomson, 1977).

Arnott & Small (1994) made an extensive survey about the most famous transport paradoxes. The Downs-Thomson is a counterintuitive answer to a very simple question: If urban road capacity is increased, does this result in some improvement in traffic speeds, or does it make congestion worse?

Shortly, the answer given by the Downs-Thomson Paradox (Downs, 1962 ; Thomson, 1977; Mogridge, 1986, 1987) is that an increase in road capacities, by causing shifts from public transit to private transport, could lead to a new traffic equilibrium where total transport costs are higher. The consequence is then a decrease in welfare level for the conurbation.

The argument is that, by implementing an additional road capacity (eg a new route or more generally a new transport alternative), road speed increase, attracting public transit users towards road transport. The consequence is, as public transit traffic decreases, there is a loss of revenue for public transit operator, who, in the absence of subsidies, might raise fare or cut service. As Mogridge, 1987 wrote : "*This states that, in congested situation, the equilibrium travel costs will rise if road capacity is increased, if the cost of collective network rises as flow falls. It follows that increasing road capacity in congested situations is counterproductive*"<sup>1</sup>.

This paradox regained some interest with the analysis of Martin H. Mogridge in the 80s, because what was called "Mogridge conjecture" was an important argument for implementing urban pricing in London city<sup>2</sup>. The Mogridge's conjecture was that "*in conditions of suppressed demand, the speed of the road network is determined by the speed of the high-capacity network (rail, bus, etc.)*" (Mogridge, 1997 ; Mogridge, 1986).

More precisely, this paradox is the consequence of users equilibrium and of Wardrop's first principle (users reach an equilibrium where travel costs is equal for each alternative). Such a paradox is the consequence of induced/latent demand effect (Arnott & Small, 1994 ; Abraham & Hunt, 2001 ; Nolan, 2001 ; Afimeimounga et al., 2005).

To our knowledge, the only empirical evidence about Downs-Thomson had been given by Mogridge, 1990, 1997. Mogridge asserted that the decrease in speeds in London centre was the consequence of Downs-Thomson Paradox, e.g. that increase in road network capacity over time causes decline in traffic for mass transit (train), the global consequence being a growth of travel times for both users (see table 1 below)

Insert table 1

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<sup>1</sup>Mogridge, 1997 p. 9.

<sup>2</sup>« *The first (paradox) is that in congested conditions, building more road capacity for cars makes both motorists and users of public transport worse off. By encouraging a shift from public transport to cars it fills up the new road space, makes public transport less frequent and more expensive, and results in a new equilibrium that is slower for all. The second paradox follows from the first: taxing the inefficient road user (the motorist) and subsidising the efficient (on buses and trains) will make all travellers better off* » *The Times*, March, 17th, 2000.

Mogridge conjectures then that a decrease in road capacities, or better, an increase in mass transit capacity, could shift road users to train and can therefore decrease total travel times for big conurbations. His argument was one important element in favour of London urban pricing that had been implemented some years after.

The problem of such empirical evidence is that it is almost impossible here to distinguish precisely the variables that could influence average travel time, because the *ceteris paribus* assumption is not respected. That is one major reason for using experimental economics in order to give empirical evidence to DT paradox, because in the lab, it is possible to isolate the impact of changing road capacity on users' choices and then on total travel times. The main question concerning implementation in the lab is about the accurate theoretical model to obtain experimental congestion, that is to say a divergence between private cost and social cost of transport as a consequence of a coordination problem between transport users.

### 3 Theoretical model: The Double Market Entry Game

Our theoretical model is an extension of Market Entry Game (Selten and Güth, 1982 and Gary-Bobo, 1990). In our game, two types of agents, A and B have to make choices. The individual A is the public transit operator, and has to choose capacity level for market 2 (public transit). Then, individuals B (transport users) have to choose between market 1 (road transit) and market 2 (public transit). We will assume that market 1's capacity is given for transport users and that market 2's capacity is chosen by public transit operator. Our game is sequential, e. g. individual A chooses capacity of market 2, other parameters being common knowledge. In the second step, users know capacities for each market, and choose to enter market 1 or market 2. Using backward induction, we will assume that, if public transit operator knows how players B choose between market 1 and market 2, he should choose the capacity level that maximizes his payoff.

#### 3.1 Users' traffic equilibrium (one-shot game)

Players B have to choose simultaneously between the option X (Road or Market 1) and Y (Public Transit or Market 2). Differing from the usual MEG, there is no outside option which gives a given payoff for sure (see above).

The individual payoff for a user choosing road transit is<sup>3</sup>:

$$\pi_1^i = k_1 + r_1 (c_1 - m_1) \quad \text{if } \delta_i = X \quad (1)$$

whereas the individual payoff of using public transit is:

$$\pi_2^i = k_2 + r_2 (c_2 + m_2) \quad \text{if } \delta_i = Y \quad (2)$$

Where  $c_1$  and  $c_2$  are respectively the capacities of road and public transit,  $m_1$  and  $m_2$  are respectively the number of users choosing market 1 (road) and market 2 (public transit),  $r_1, r_2, k_1, k_2$  are positive parameters with  $r_1 > r_2$  and  $k_1 > k_2$ . All these parameters are to be known by all participants B before they choose which market to enter<sup>4</sup>. Such information is also given to participant A (the operator for market 2).

Constraints are:

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<sup>3</sup>The market 1 technology is similar to the payoff for entering on market in a usual Market Entry Game (see Erev & Rapoport, 1998).

<sup>4</sup>Our game differs from Rapoport et al., 2000 *Two Market Entry Game* (TMEG) in one major respect: Entering first or second market implies a decrease in individual payoffs for both markets in TMEG, whereas in our DMEG case, more entrants on market 2 increase individual payoff for each entrant.

$$m_1 + m_2 = n \quad (3)$$

or equivalently

$$m_2 = n - m_1 \quad (4)$$

and that

$$c_1 + c_2 < n \quad (5)$$

Where  $n$  is the finite number of transport users.

In this model, using road transit is supposed to create a negative externality, as in the usual MEG, whereas using public transit is supposed to create a positive externality. This positive externality is linked to the fact that, if capacity is fixed, the increase in public transit enables to increase frequencies and then decrease time travel cost (see Arnott and Small, 1994<sup>5</sup>).

Users equilibrium is reached when:

$$k_1 + r_1 (c_1 - m_1) = k_2 + r_2 (c_2 + m_2) \quad (6)$$

Then, combining equns. (8) and (10), and as  $-r_1 + r_2 \neq 0$ , we have:

$$m_1 = \frac{k_1 - k_2 - r_2 (n + c_2) + c_1 r_1}{r_1 - r_2} \quad (7)$$

And consequently

$$m_2 = \frac{1}{r_1 - r_2} (k_2 - k_1 + n r_1 - c_1 r_1 + c_2 r_2) \quad (8)$$

The entry rate (traffic) on market 1 (market 2) is respectively increasing (decreasing) with  $c_1, k_1, r_1$  and  $n$ , decreasing with  $c_2, k_2$  and  $r_2$ . Of course, such a theoretical prediction holds for a continuum of agents. In the experimental game, theoretical predictions will be made without this assumption (see below).

### 3.2 Optimal choice for public transit operator

We assume that the profit  $\pi$  for public transit operator is simply the difference between the number of public transit users and the capacity he chooses, e.g.:

$$\pi = m_2 - c_2 \quad (9)$$

Thus, replacing  $m_2$  with equ. (8), and using eqn (11), we obtain

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<sup>5</sup>"If more people take the train, then trains run more frequently, saving people some waiting time at the station", p.4 . Such a property is a technological property of all types of mass transit, as it was shown by Mohring, 1972.

$$\begin{aligned}\pi &= \left( n - \left( \frac{k_1 - k_2 - r_2(n + c_2) + c_1 r_1}{r_1 - r_2} \right) \right) - c_2 = \\ &= n - c_2 - \frac{k_1}{r_1 - r_2} + \frac{k_2}{r_1 - r_2} + n \frac{r_2}{r_1 - r_2} - c_1 \frac{r_1}{r_1 - r_2} + c_2 \frac{r_2}{r_1 - r_2}\end{aligned}$$

If we assume that  $\frac{r_2}{r_1 - r_2} < 1$ , the optimal solution is a corner solution where  $c_2$  equals zero.

Then, in the one-shot game, the theoretical prediction based on pure strategy Nash equilibrium is that the operator chooses the minimum capacity level and consequently, users coordinate to enter for some of them on "road market" and for the others on "public market", entry rates for road and public transit being given respectively by eqns (11) and (12). If players know that the one-shot game is to be repeated a finite number of times, then the equilibrium for the one-shot game should be implemented at each period<sup>6</sup>.

### 3.3 Downs-Thomson (DT) Paradox

The Downs-Thomson Paradox is a situation where welfare is to be decreased when road (market 1) capacity increases, the other market (public transit) capacity remaining constant. This occurs because too many users shift from road market to public transit market.

The level of welfare in the Double Market Entry Game is simply the sum of all players payoffs, that is:

$$W = (m_2 - c_2) + m_1(k_1 + r_1(c_1 - m_1)) + m_2(k_2 + r_2(c_2 + m_2)) \quad (10)$$

Or, equivalently, given eqn (8)

$$W = (n - m_1 - c_2) + m_1(k_1 + r_1(c_1 - m_1)) + (n - m_1)(k_2 + r_2(c_2 + n - m_1)) \quad (11)$$

Furthermore, we obtained previously the expression (11) on entry rate in market 1 (road), which could be replaced in the former equation giving welfare. After simplification, it gives:

$$W = \frac{1}{r_1 - r_2} (k_2 - k_1 + nr_1 - c_1 r_1 - c_2 r_1 + 2c_2 r_2 + n^2 r_1 r_2 - nk_1 r_2 + nk_2 r_1 - nc_1 r_1 r_2 + nc_2 r_1 r_2) \quad (12)$$

Assume that capacity  $c_2$  is to be constant, since we are for the moment not interested in the behavior of player A. Let call  $W_{HIGH}$  the level of welfare obtained in a situation where road capacity is high, say  $c_1$  and  $W_{LOW}$  the level of welfare obtained in a situation where road capacity is low, say  $c_1^*$ . We have then  $c_1 > c_1^*$ .

If the DT Paradox is to occur, then an exogeneous increase in road capacity should decrease welfare level. If we compute the variation in welfare level from low capacity to high capacity, we have, after manipulation:

$$\Delta W = W_{HIGH} - W_{LOW} = -r_1 \frac{c_1 - c_1^*}{r_1 - r_2} (nr_2 + 1) < 0 \quad (13)$$

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<sup>6</sup>Nevertheless, it is fair to remark that in the repeated game, such a prediction does not hold necessarily (see Gaechter & Falk, 2002, p5). One argument is that if players are from different "types", the game is of incomplete information which might rise possibility for playing cooperative behaviour. Kreps, Milgrom, Roberts and Wilson, 1982 show that, even if there is a small probability that the adversary is, e.g., a "tit for tat" player, cooperative play can be supported until the final period.



This expression is negative, since all parameters are positive in the DMEG, i.e. increasing road capacity causes a decrease in welfare, which gives a theorem and its corollary.

**Theorem 1** *In the Double-Market Entry Game, an increase in market's 1 capacity, the other market capacity remaining constant, will decrease level of Welfare by shifting users from market 2 to market 1 (Downs-Thomson Paradox)*

**Corollary 2** *A decrease in Market's 1 capacity will increase Welfare level.*

Such a theoretical result is precisely what is to be tested in our experimental treatments.

## 4 Experimental design

In this section, we present the different experimental treatments that have been implemented in the lab, and therefore, given the specific values we had for parameters, we give the experimental predictions implied by the theoretical model presented above.

### 4.1 Experimental treatments

In each session, a group of 15 subjects participate to the double market-entry game described above. At the beginning of the experiment, a randomly chosen subject plays role A and the others subjects play role B. Roles remain constant throughout the session (partners design, one subject A and 14 subjects B). Each participant plays 40 periods of a two-stage game. For each period, the two-step game is the following: In the first step, subject A choose a positive integer number concerning level for market 2, from 1 to 11. Then, participants B are informed about A's choice, and have subsequently to choose to enter market 1 or market 2. At the end of the period, all participants are informed about the current number of entrants on market 1 and market 2, about the payoffs of each participant (payoffs are symmetrical for participants B). Then, a new period begins.

In each session, participants plays two subsequent games for 20 periods. Instructions specified that they will play two games of 20 periods subsequently. The only difference between the two games is the capacity of market 1, which could be high or low (see table below about the parameters that have been used). For 20 periods, participants play first low capacity and then high capacity in some sessions (condition ADD) and, in other sessions, participants play first high capacity and then low capacity (condition DEL). There is no contextualization or framing in the instructions that do not talk about transport. Instructions refer to option X (market 1 or road) and option Y (market 2 or public transit) that has to be chosen by participants B. Participants B are aware about the value of  $c_2$  chosen by participant A, which is not described to be an operator who has to choose a given capacity. At the end of the experiment, all participants answer to post-experimental surveys, one to elicit individual risk aversion<sup>7</sup> and the other to have some information about socioeconomic characteristics and to have some debriefing from subjects. The parameters that had been implemented in the experiment are the following:

Insert Table 2 about here

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<sup>7</sup>As many experimenters, we use the Holt-Laury procedure to elicit the level of Constant Risk Relative Aversion (CRRA) index. For more details, see Holt & Laury, 2002.

In the experiment, participants payoffs are given in points, and an exchange rate in Euros is announced for each point to be gained finally at the end of the experiment. In order to avoid income effect, and because losses were possible in a given round for any participants, 4 rounds among the 40 that have been played have been randomly chosen to determine the final payoff, and we add as usual a participation fee.

## 4.2 Theoretical equilibriums

In this particular kind of game (multiple stage games with observed actions), the equilibria are obtained by implementing Subgame-Perfect Equilibrium (SPE) method. A strategy profile is a subgame-perfect equilibrium if it represents a Nash equilibrium of every subgame of the original game. As often, we use the common method of backward induction in order to determine subgame perfect equilibria. Given our particular parameters (see table 2), the SPE corresponds to a capacity choice of  $c_2 = 1$  for player A and to an entry rate of 6 players B on market 1 (road), e.g. 8 players B on market 2 (public transit) when road capacity is equal to 3 (*treatment LOW*). When road capacity is equal to 6 (*treatment HIGH*), the optimal strategy remains to choose  $c_2 = 1$  for player A, but the entry rates are changing, giving 10 players B on market 1 and consequently 4 players B on market 2. Of course, there is also different equilibria for subgame B depending on A's choice about capacity of market 2.

For instance, assume we have 7 players B on market 1 and 7 players B on market 2 after player A chose  $c_2 = 1$ . Each player B gains 2 points. This is not a Nash equilibrium since a player B could gain 0.25 point if she deviate and choose Y (2.25 points for option Y and 3 points for option X). At this point, we have 6 players B on m1 and 8 players B on m2. If an additional player B deviate to choose Y, he will gain 0.25, obtaining 2.5, but leaving 3 not to choose X. Then, for  $c_2 = 1$ , Nash Pure Strategy equilibria for subgame B imply 6 players B choosing X and 8 players B choosing Y.

For  $c_2$  levels higher than 1, the number of entrants on  $m_1$  decreases.

The following table summarizes theoretical predictions given the specific values of parameters chosen in the experimental design.

Insert table 3 about here

The increase in road capacity makes road choice more attractive, implying 4 additional users in HIGH treatment compared to the LOW treatment. The consequence is that payoffs for all individuals decrease, and consequently the efficiency level at the asymmetric Pure Nash Equilibria is lower in the HIGH treatment. As the maximum level of welfare should be obtained by choosing maximum capacity for public transit, with no user entering on road, the change in road capacity does not affect efficiency level.

## 5 Experimental results

Sessions have been held in LABEX, Rennes, from January to April 2008, under the ZTREE platform (Fischbacher, 2007). The average duration of a session was 1h30 for an average payoff of 15 euros for participants B, 20 euros for participant A. There had 16 sessions of 15 participants, ie 240 subjects. 8 sessions were made in the ADD condition and also 8 sessions were made in the DEL condition.

## 5.1 Capacity choices for public transit

Here we analyse subject A' choice about the capacity level for market 2 (public transit) and its determinants. Let remind that theoretical predictions given above indicate that public transit operator capacity choice should not be influenced at the end by the exogeneous road capacity. In all treatments, subject A should choose the minimum capacity in order to maximize her profit.

The main results concerning capacity choice by subject A are the following. First, there is no significant difference about the level of capacity chosen by A for public transit for treatments HIGH and LOW, as theoretical model suggests. Second, the average capacity chosen by A tend to be significantly higher than levels to be predicted by theoretical model. But, it decreases with repetition, suggesting some kind of learning. Finally, it has to be noticed that there is considerable heterogeneity within and between the individual data.

Actually, average capacity chosen by subjects A is given in the following table. For ADD condition, the average capacity for market 2 is around 3.79 whereas it is 3.75 for DEL condition. The data analysis in the table below indicates that individual behaviours are quite heterogeneous, especially in the DEL condition for LOW treatment, where some subjects choose repeatedly the minimum capacity whereas other subjects tend to focalise on a "middle-point" level for capacity  $c_1 = 6$  (HIGH treatment).

Insert table 4

The average capacity chosen in LOW treatments is not significantly different from the average capacity chosen in HIGH treatments. A bilateral Mann-Whitney Wilcoxon rank-sum test about the equality of average capacity chosen in the ADD condition for LOW treatment to the average capacity chosen in the DEL condition for HIGH treatment could not reject the assumption ( $z = -0.630$ ,  $p = 0.529$ ). A similar test assuming the equality of capacity chosen for LOW treatment in the DEL condition to capacity chosen for HIGH treatment in the ADD condition gives comparable results ( $z = -0.421$ ,  $p = 0.674$ ).

If a within-subjects comparison is conducted, it is possible to observe that average capacity tend to be higher in the first treatment compared to the second treatment, as it is suggested by graphs below, especially for the DEL condition (see also table 4 for other evidence).

Insert figure 1 about here

Insert figure 2 about here

Such an intuition is confirmed by non parametrical analysis (Wilcoxon matched pairs test). In ADD condition, there is a significant difference about capacity chosen by A depending on capacity level  $c_1$ . Average capacity is higher in « LOW » treatment compared to « HIGH » treatment (Wilcoxon matched-paired sign rank, bilateral,  $z = 2.106$ ,  $p = 0.0352^{**}$ ).

In DEL condition, there is also a (weak) significant difference LOW and HIGH treatments (Wilcoxon,  $z = -1.820$ ,  $p = 0.0687^{*}$ ), average capacity chosen by subject A being higher in HIGH treatment compared to LOW treatment.

Such a result is confirmed if data are pooled together (sessions ADD and DEL) and if a Wilcoxon matched-pairs signed rank test is conducted. The assumption is that average capacity chosen by A during the first 20 periods is equal to the average capacity chosen by A during the last 20 periods. Such an assumption is strongly rejected (bilat. Wilcoxon,  $z = 2.795$ ,  $p = 0.0052^{***}$ ),

suggesting clearly that average capacity chosen in the first 20 periods is significantly higher than the average capacity chosen in the last 20 periods. This temporal trend is confirmed by parametrical analysis. We conduct a Panel Regression about individual choices for market 2's capacity (left censored, Tobit Analysis, Random Effects GLS). Results are given in the following table.

Insert table 5

The above regression indicates that market 1 capacity plays an ambiguous role: The coefficient is positive and significant when data are pooled, but becomes non significant when capacity choice is analyzed for each condition. Given the limited number of data, we have to be cautious with econometric results. Nevertheless, some variables play a key role, as risk aversion level and time (period). There is a clear trend to have a decrease in capacity level chosen by A from period to period, as non parametrical analysis suggested above. Moreover, the more risk averse participant A is, the lower capacity she chooses.

## 5.2 Entry on markets

Entry rate on markets is obviously related to capacity on each market. The theoretical model predicts that when road capacity is LOW, entry rate on road should decrease whereas higher levels of capacity for public transit decrease it. Actually, the important result is that entry on market 1 is higher when capacity for this market is higher. Figures 3 and 4 give the average entry rate on market 1 (road) respectively for ADD condition and for DEL condition.

Insert figure 3 about here

Insert figure 4

Figures above indicate clearly that entry rate increases when road capacity is to be increased. Such empirical result is statistically significant, as non parametrical tests show. In ADD condition the average entry rate is 6.07 in the LOW treatment compared to an average entry rate of 9.43 in the HIGH treatment (road capacity is doubled). A within subject Wilcoxon test is significant at the 5% level ( $z = -2.521$  ;  $p = .0117$ ). That is also the case in DEL condition, where average entry rate tends to be higher in HIGH treatment (the average entry rate is around 6.41 in LOW treatment compared to 8.63 in HIGH treatment, the Wilcoxon matched paired sign-rank test indicates  $z = -2.524$  ;  $p = .0116$ ).

Such an empirical evidence is also clearly demonstrated when we implement between subjects comparison. If the entry rate of the LOW treatment in the ADD condition is compared to the entry rate in the HIGH treatment for the DEL condition (these two treatments constitute both the first part of the experiment for these participants), the entry rate are respectively 6.07 and 8.63, which is significant at the 1% level (bilateral Mann-Whitney test,  $z = -3.366$ ,  $p = .0008$ ). The same result is obtained by comparing average entry rate in each group for the HIGH treatment in the ADD condition and average entry rate per group for the LOW treatment in the DEL condition (such treatments constitute the final part of the experiment). A bilateral Mann-Whitney indicates clearly that entry rate when (road) capacity is high is statistically higher than entry rate when capacity is low ( $z = +3.363$  ;  $p = .0008$ , significant at the 1% level).

Another result is that entry rate on road tends to increase over time, indicating some learning process for participants B. Throughout the repetition of game, they clearly understood that they tend to underenter on road market, and they change gradually their choice to match Pure Strategy Nash equilibrium entry rate. But such a result is statistically significant only for the HIGH treatments: Entry rate in ADD condition for the high treatment (part 2 of the experiment) is higher than the entry rate in DEL condition for the same treatment (9.43 compared to 8.63, bilateral Mann-Whitney,  $z = +2.298$  ;  $p = .0027$ , significant at the 1% level). But such a result has to be cautiously interpreted, because it could also be the consequence of participants heterogeneity.

In order to have more details about participant B behaviour, we conduct a parametrical analysis concerning variables that could influence B's choice. This parametric analysis explains factors that influence the probability  $p$  to enter on market 1 (road) for a participant B in period  $t$  (Panel Data analysis). Obviously, probability  $(1 - p)$  will be the probability not to enter on market 1, and therefore to enter on market 2, since there is no outside option in our game. The results of this probit analysis are given in the following table.

Insert table 6 around here

The dependant variable is the probability to enter on market 1 in period  $t$  for a participant B. The explanatory variables are the following.  $c_1^t$  is the capacity of market 1 in period  $t$ ,  $c_2^t$  is the capacity of market 2 chosen by participant A in period  $t$ , and  $c_2^{t-1}$  is the same lagged variable.  $m_1^{t-1}$  is the observed number of entrants in market 1 at the last period, *RISK* is the level of CRRA index for the participant<sup>8</sup>,  $\pi_i^{t-1}$  is his payoff in the last period, *COND* is a dummy variable concerning experimental condition (=1 if ADD and =0 if DEL) and  $t$  relates to the time variable.

When we analyse entry for B subjects, we find some intuitive results, that are in line with our theoretical predictions. Entry rate on a market depends positively on its capacity and negatively of the other market capacity. Moreover, previous choice of capacity for participant A influences entry choice for participant B: The more she chose in the previous period, the less he enters on road. An other interesting result concerns users' coordination during the experiment. The number of entrants in previous period increases the probability to enter in the current period (significant at the 5% level for DEL condition and for the pooled data, but not for the ADD condition). Subjects B anticipate that high previous entry rate implies low entry rate for the current period and vice versa (they anticipate some cyclical oscillation around an average entry rate on road). There is also learning processes, since entry on road tends to increase with repetition (subjects understand that road choice is risky but no so much as anticipated (possible negative payoffs)). As before, such a variable is significant at the 5% level for DEL treatment and for pooled data, but not for ADD treatment. Then the above result is confirmed by parametric analysis. Last but not least, the more participant risk averse, the less the probability to enter.

### 5.3 Payoffs and Welfare

As road capacity grows, shifts from public transit to road choice may first decrease congestion risk and so increase payoffs for those who choose road. All things being equal, higher capacity should increase group welfare. Of course, such assumption does not hold, since additional users

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<sup>8</sup>Actually the number of safe lotteries chosen by the participant in our ex post survey, this survey being based on Holt & Laury, 2002.

on road may decrease the level for the positive externality of public transit. Moreover, if public transit operator reduce her capacity in order to decrease her operating costs, her profit may decrease also. At the end, these two negative effects could decrease welfare level for the entire group.

### 5.3.1 Profit for Public Transit Operator

We have observed previously that increasing road capacity does not change significantly capacity choice for subject A. But, it changes drastically the distribution of subjects B by encouraging them to choose road more frequently. The consequence is that, clearly, profit for A (i.e.  $M_2 - c_2$ ) decreases.

Watching the experimental data, the important result is that profit for B is higher in the LOW treatment compared to the HIGH treatment (see figure 5).

Insert figure 5

That is precisely one component of the Downs-Thomson paradox. Increasing road capacity will make public transit users shifting to road, which precisely decreases revenue for operator<sup>9</sup>. This empirical result is clearly established with non parametrical tests, for within and between-subject analysis. A Wilcoxon matched-paired sign rank test for each condition establishes a significant difference about A's profit between LOW and HIGH treatments (bilateral,  $z = 2.521$ ,  $p = 0.0117$ , significant at the 5% level). The positive value of  $z$  means that A's profit is significantly higher in LOW treatment for both conditions. Such a result is confirmed by between-subject analysis. A Mann-Whitney Rank Sign Test about the equality of A's profit for treatment LOW for ADD condition and for treatment HIGH for DEL condition is strongly rejected ( $z = 3.046$ ,  $p = 0.0023$ , significant at the 1% level). We find a comparable result by assuming the equality of average A's profit for treatment LOW for DEL condition and for treatment HIGH for ADD condition ( $z = 3.363$ ,  $p = 0.0008$ , significant at the 1% level).

### 5.3.2 Group Welfare

The following graphs show the evolution of total group payoff throughout the periods of the experiment. The total group payoff for a given group at period  $t$  is:

$$W^t = \pi_A^t + m_1^t (\pi_{B1}^t) + (n - m_1^t) \pi_{B2}^t \quad (14)$$

Average group payoff depending on period is given in figure 6. In this figure, the green dashed-line recalls maximum efficiency level, while the red dashed lines recall efficiency level predicted by Pure Asymmetric Nash equilibria.

Insert figure 6

The average Group payoff for LOW treatment in ADD condition is 42.6 (indicated by the blue line), which is remarkably near Nash equilibrium efficiency level. In the HIGH treatment, average

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<sup>9</sup>Arnott et al., 1993 wrote p.148 "If road capacity is now expanded, users will shift to the road until it is as congested as before. If the railway has to balance its budget, the loss of revenue will force it to increase fares and cut service (...)".

group payoff is around 32, which is higher than Nash equilibrium level (28), but not significantly. Clearly, welfare level decreases when road capacity is to be increased. A non parametrical test confirms this intuition (Wilcoxon,  $p = 0.0078^{***}$ ) in ADD condition.

Insert figure 7 about there

In the DEL condition, the average group payoff is around 39.8 for HIGH treatment, to be compared to 38.7 in LOW treatment. Actually, there is no significant difference about welfare between the treatments. The decrease in road capacity does not succeed to increase significantly payoffs both for subjects B and subject A (theoretically, NE should give 28 points in HIGH treatment and then 40 points in the LOW treatment). This is because Group payoff in the first treatment (HIGH) is quite high compared to the Nash prediction (around 40 on average to be compared with 28 theoretically). This relatively high level of welfare results essentially from participant B's behaviour. As he is not extracting all the rent (he should gain 3 points in the HIGH treatment and he actually gains 1 point) by choosing high capacity levels, his payoff is very low. But these higher capacity levels do not give higher entry rate for market 2 (compared to Nash Perfect Subgame equilibrium), which is around 6. That means participants B who choose market 2 increases their payoff because capacity is higher for the market they choose.

The last result is about the interaction between participants A and participants B. It is possible to see that participants B coordinate quite well on subgame Nash equilibrium after participant A chose market 2 capacity, as it can be viewed in figure 8 below.

Insert figure 8 about here

The figure gives the empirical average entry rate compared to theoretical entry rate given by Pure Strategy Nash equilibrium for the subgame of participants B<sup>10</sup>. The first observation is that empirical entry rate is close to theoretical one, whatever exogeneous capacity for market 1 (low or high), e.g indicating a high level of coordination for participants B. Another observation is that average observed entry rate tends to be higher compared to theoretical one in the LOW treatment, which is not the case in HIGH treatment. Such a result is similar to what was already observed by Camerer & Lovo (1999) in the usual MEG, who observe that there is overentry when capacity is low and underentry when capacity of the market is high.

## 6 Concluding comments

The aim of this paper was to give empirical, and more precisely, experimental evidence to a well-known phenomenon discussed since years in transport economics, the Downs-Thomson Paradox. To this end we build a theoretical model inspired on the usual Market Entry Game and based, firstly, on an individual choice between two markets, and, secondly, on the fact each market generates either a negative externality or a positive one. The third originality in our model is to implement an endogenous choice of capacity for one of these two markets before individuals (users) have to enter, the other market capacity being exogeneous. The theoretical equilibrium

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<sup>10</sup>The dashed line has to be interpreted cautiously, since for some capacity levels of market 2, there is more than one theoretical entry rate predicted by Pure Strategy Nash equilibrium. We took the "average" theoretical entry rate in the figure for convenience.

(pure strategy Nash) is such that, given the particular subgame for users, the operator should choose the minimum capacity for his market, and for this level, given a certain fixed capacity for the other market, users allocate themselves between the two markets. An exogenous shock concerning the capacity of the first market should give an incentive for users to switch from one market to the other, the optimal strategy of the operator being the same: When exogenous capacity increases, users flow from market 2 to market 1 and *vice versa*. The consequences of such an exogenous shock are that, first, on operator's revenue - it decreases when exogenous capacity increases - and second on total welfare for the group - it decreases when exogenous capacity increases since total users cost increases. That is, our simple theoretical model predicts Downs Thomson Paradox. To test it, we implement experimental sessions in which some subjects are first confronted to a low capacity level and second to a high capacity level (ADD condition) and for other subjects, it is the contrary (DEL condition). The first condition corresponds precisely to Downs-Thomson situation, whereas the reverse condition is closer to Mogridge conjecture.

The results we obtained are the following. Firstly, we observe that Downs-Thomson Paradox is produced in the laboratory, which gives empirical support for such a phenomenon. Secondly, we nevertheless do not observe that decreasing market capacity exogeneously does produce some improvement in welfare level.

The second result is that, for a given vector of capacity levels, users coordinate remarkably well on average around the entry rate predicted by pure strategy Nash equilibrium for the users' subgame. This result is in line with former results obtained in experimental studies for Market Entry Games, but we have to notice that our game is almost more complex for subjects, which precisely make coordination problem more difficult to solve for them.

The third important result is that operator does not choose the minimum level of capacity, far from it, and that his choice responds very little to exogenous road capacity. Such a result is obviously linked to the repeated partners design we implement in the lab, since it enables both reciprocity effect and reputation effect that might increase the level of capacity he chooses.

In terms of transport policies, what our results indicate is that, first, as was saying Roy Kienitz (executive director of the Surface Transportation Policy Project, cited by Litman, 2005): "*Widening roads to ease congestion is like trying to cure obesity by loosening your belt*". It might be useless to solve road congestion by increasing road capacity, at least in the short term. Secondly, policy makers should be cautious about the temptation to solve congestion problems by thinking that a decrease in road capacity (or an increase in public transit capacity, the road capacity being constant) might reduce total transport costs.

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Table 1. Average speed for private car and rail in London centre

**Table 6** Mean direct journey speed by sector by car and rail for journeys beginning 15 km from centre, morning peak-hour (7–1-am), central destinations within 6 km of centre

<b>Sector and Mode</b>	<b>1962 (km/hr)</b>	<b>1971 (km/hr)</b>	<b>1981 (km/hr)</b>
1 car	15.70	15.15	15.33
rail	15.29	14.84	13.54
2 car	18.49	16.76	15.67
rail	15.92	15.62	14.43
3 car	18.07	18.01	16.05
rail	16.15	16.44	14.64
4 car	17.80	17.81	17.09
rail	16.41	15.77	15.26
5 car	17.27	16.81	15.22
rail	15.87	15.71	14.30
6 car	16.55	16.16	15.10
rail	14.58	14.57	13.99
Total car	17.19	16.89	15.66
rail	15.63	15.42	14.19

Source : Mogridge (1997)

Table 2. Experimental sessions

parameters			sessions	conditions	number of sessions	participants
	LOW treatment	HIGH treatment	ADD	treat 1 + treat2	8	120
$k_1$	6	6	DEL	treat 2 + treat 1	8	120
$k_2$	0	0	Total		16	240
$r_1$	1	1				
$r_2$	0.25	0.25				
$c_1$	3	6				
$c_2$	endogenous	endogenous				

Table 3. Theoretical predictions (asymmetric Pure Nash Equilibria)

treatment	$c_2$	$m_1$	$m_2$	$\pi_A^i$	$\pi_B^i$ if $\delta^i = X$	$\pi_B^i$ if $\delta^i = Y$	$W_{Nash}$	$W_{Max}$
$c_1 = 3$ (LOW)	1	6	8	7	3	2.25	43	90.5
$c_1 = 6$ (HIGH)	1	10	4	3	2	1.25	28	90.5

Table 4. Capacity chosen by subject A per group

capacity $c_2$ (mean and s.d., individual data)			
cond.	group	LOW	HIGH
ADD	1	2.55 (3.33)	1.9 (2.29)
	2	3.35 (2.21)	3.6 (2.70)
	3	5.15 (0.86)	4.65 (0.59)
	4	4.1 (2.31)	3.6 (2.56)
	5	4.5 (2.65)	2.7 (2.11)
	6	3.05 (2.28)	3.25 (2.53)
	9	5.75 (1.37)	3.95 (1.64)
	10	5.1 (2.31)	3.45 (2.74)
	average (s.d)	4.19 (2.47)	3.39 (2.33)
DEL	7	1 (0)	1.5 (2.01)
	8	1 (0)	2.75 (3.23)
	11	3.9 (2.75)	4.25 (2.67)
	12	1.35 (0.81)	3.65 (3.08)
	13	6 (1.38)	5.9 (3.09)
	14	6.3 (0.57)	5.7 (2.15)
	15	1.8 (0.83)	5.8 (2.02)
	16	3.75 (1.89)	5.4 (2.74)
	average (s.d)	3.14 (2.44)	4.39 (3.02)

Table 5. Panel censored Tobit regression on individual choice for  $c_2$ 

variable	pooled data (1)	ADD (2)	DEL (3)
$c_1^t$ market 1 capacity in period t	0.208** (0.0870)	0.112 (0.218)	-0.111 (0.243)
$\pi_i^{t-1}$ payoff of subject A in period (t-1)	-0.0522 (0.0564)	0.00975 (0.0753)	-0.0977 (0.0839)
$m_2^{t-1}$ (number of entrants for market 2 in period (t-1)	0.0846 (0.0669)	-0.0711 (0.0955)	0.222** (0.0931)
COND (=1 if ADD ; 0 if DEL)	0.194 (1.128)	/	/
risk aversion level	-0.622** (0.254)	-0.133 (0.355)	-0.786** (0.358)
$t$	-0.0754*** (0.0112)	-0.0665** (0.0292)	-0.124*** (0.0323)
Constant $\beta_0$	6.521*** (1.854)	5.232** (2.046)	9.071*** (3.020)
Num. of Obs.	624	312	312
Subjects	16	8	8
Rho	0.369	0.179	0.488

\*\*\*: significant at 1%, \*\*: sign. at 5%, \*: sign. at 10%

NB: The estimated model is

$$c_2^t = \beta_1 c_1^t + \beta_2 \pi_i^{t-1} + \beta_3 m_2^{t-1} + \beta_4 (COND) + \beta_5 (RISK) + \beta_6 t + \beta_0$$

Table 6. Panel Probit Regression about choice to enter on market 1 (road) for participant B

variable	(1) pooled data	(2) ADD	(3) DEL
$c_1^t$	0.175*** (0.0139)	0.190*** (0.03)	0.190*** (0.0298)
$c_2^t$	-0.0561*** (0.00646)	-0.0414*** -0.00896	-0.0734*** -0.00951
$m_1^{t-1}$	0.0293** -0.0122	0.00685 -0.0182	0.0528*** -0.0166
$c_2^{t-1}$	-0.0190*** -0.00697	-0.0296*** -0.00962	-0.00297 -0.0103
Risk aversion	-0.0601*** -0.0193	-0.0560** -0.024	-0.0645** -0.0314
$\pi_i^{t-1}$	0.0774*** -0.0175	0.0564** -0.0256	0.0985*** -0.0243
COND	0.0231 -0.0673	/	/
$t$	0.00424*** -0.00135	0.00423 -0.00364	0.00841** -0.00371
Constant $\beta_0$	-0.555*** -0.161	-0.412** -0.205	-0.908*** -0.306
Observations	8736	4368	4368
Number of subject	224	112	112
Ln sigma2u	-1.581*** -0.122	-1.752*** -0.175	-1.418*** -0.17
Sigma u	0.454 0.028	0.416 0.037	0.492 0.042
rho	0.171 0.017	0.148 0.022	0.195 0.027

\*\*\*: significant at 1%, \*\*: sign. at 5%, \*: sign. at 10%

NB: The estimated model is

$$\Pr(\delta_i = X) = \beta_1 c_1^t + \beta_2 c_2^t + \beta_3 m_1^{t-1} + \beta_4 c_2^{t-1} + \beta_5 (RISK) + \beta_6 \pi_i^{t-1} + \beta_7 (COND) + \beta_8 t + \beta_0$$

Figure 1. Average capacity chosen by B in each period (ADD condition)

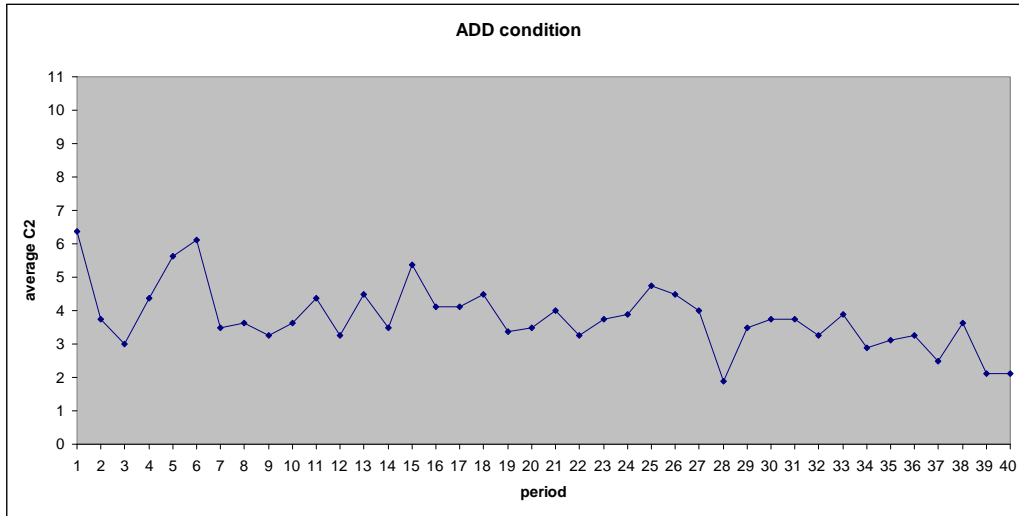


Figure 2. Average capacity chosen by B in each period (DEL condition)

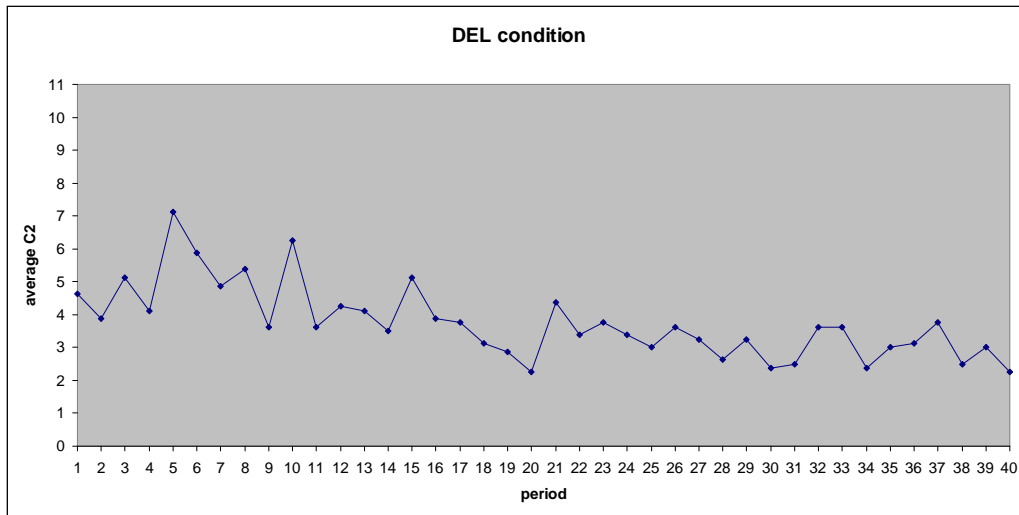


Figure 3. Average number of entrants on market 1 in each period - ADD condition

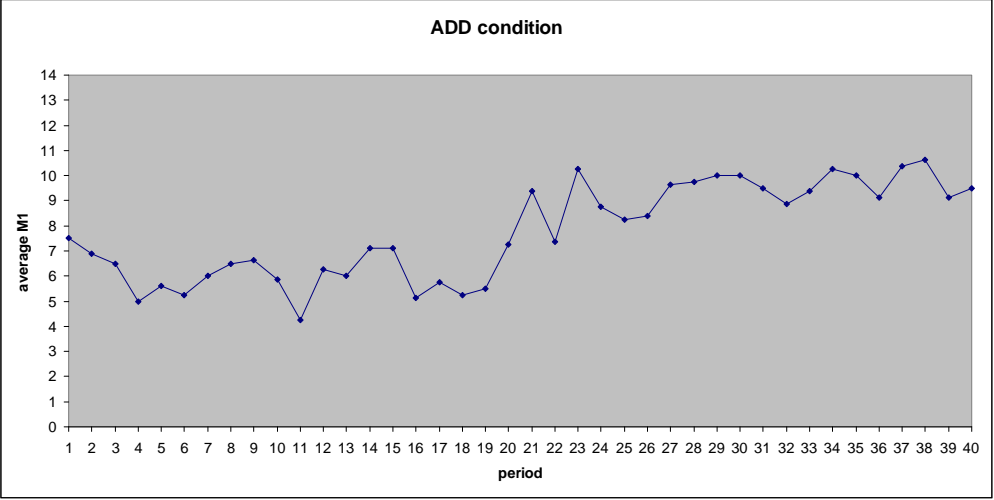


Figure 4. Average number of entrants on market 1 in each period - DEL condition

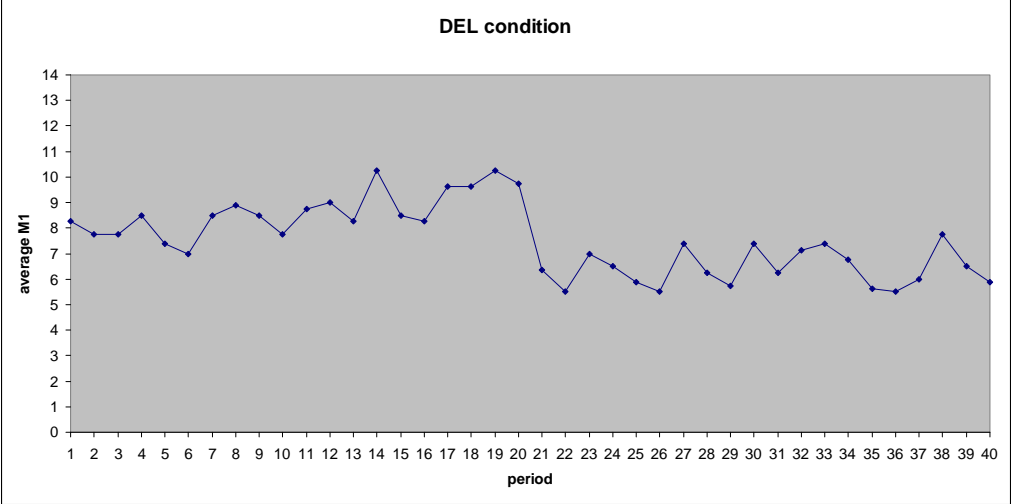




Figure 5. Average payoff for Participant B in each period - ADD and DEL conditions

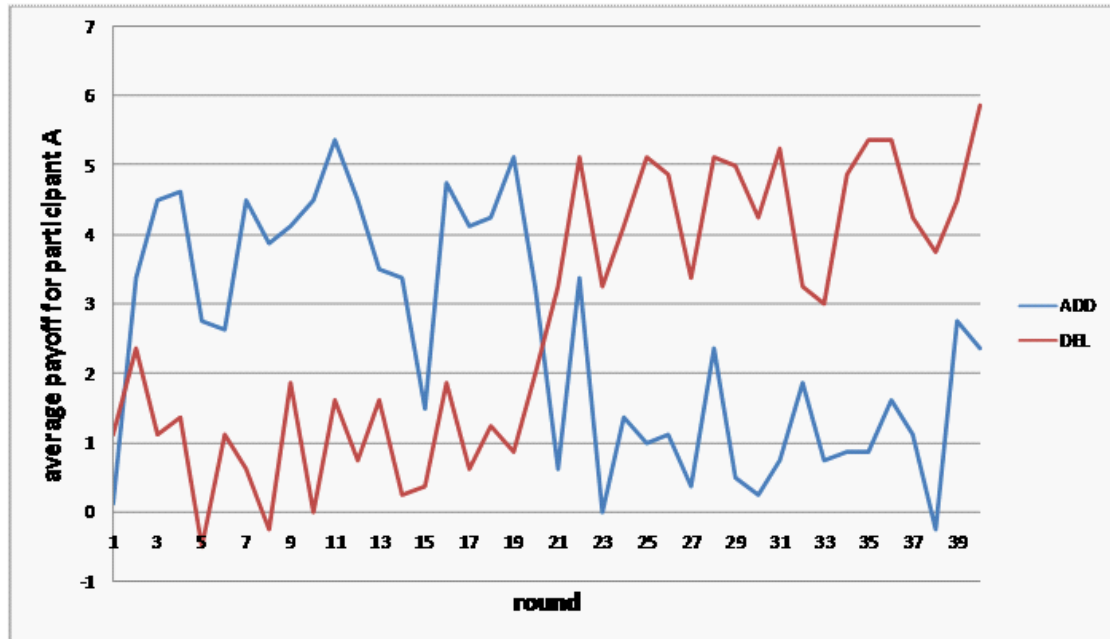


Figure 6. Average Group Payoff in each period - ADD condition

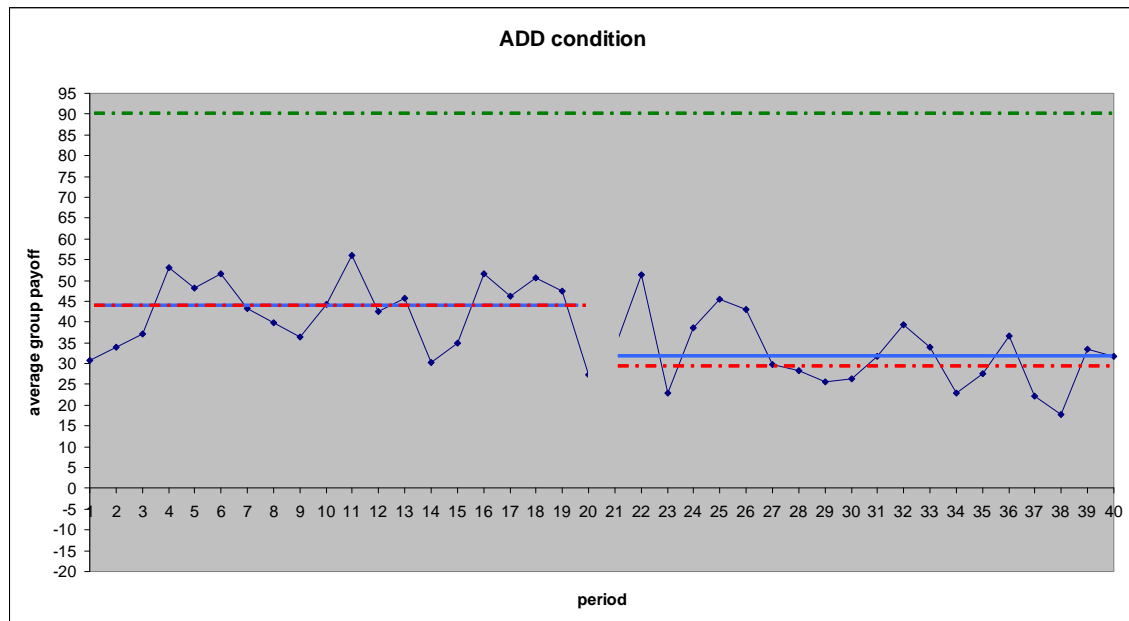


Figure 7. Average Group Payoff in each period - DEL condition

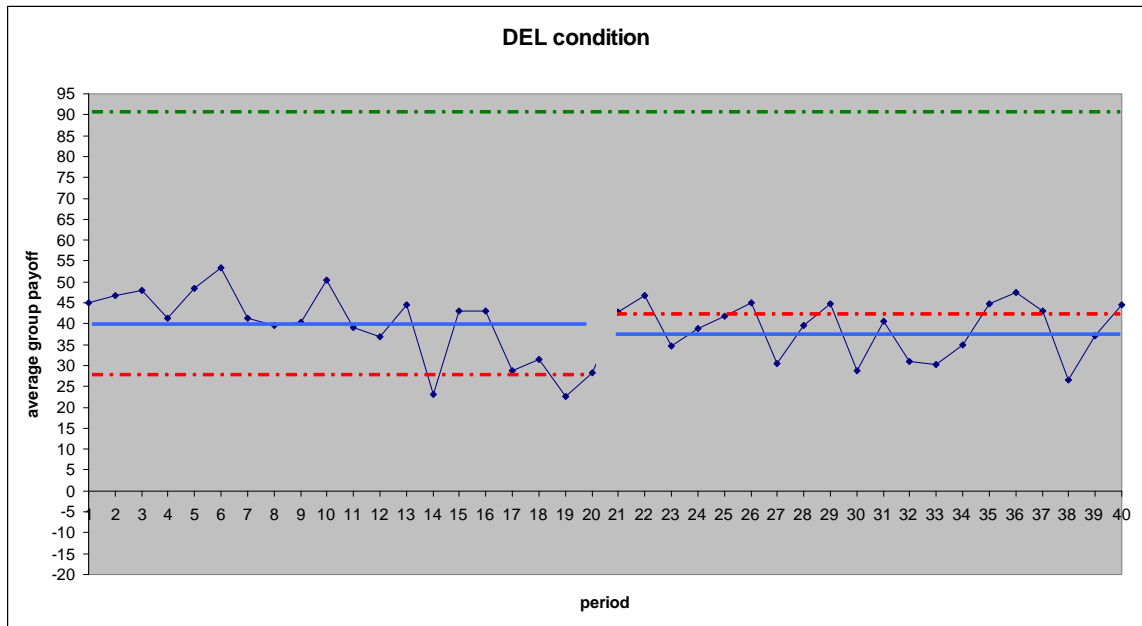


Figure 8. Entry rates on road as a function of capacity chosen by the operator (participant A)

